COMARE

Committee on Medical Aspects of Radiation in the Environment

RWMAC

Radioactive Waste Management Advisory Committee

Report on:

Potential Health Effects and Possible Sources of Radioactive Particles Found in the Vicinity of the Dounreay Nuclear Establishment

HMSO

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Contents

EXECUTIVE SUMMARY

This publication comprises two reports prepared independently by two different committees, namely the Committee on Medical Aspects of Radiation in the Environment (COMARE) and the Radioactive Waste Management Advisory Committee (RWMAC). The COMARE statement was prepared at the request of the Scottish Office and the RWMAC report prepared in response to a request from COMARE. The terms of reference of COMARE and the RWMAC and a list of members are given in Annexes 1 and 2 to this document.

These reports address the possible health implications and putative source of the radioactive particles that have been found in the vicinity of the Dounreay Nuclear Establishment.

The Second Report of COMARE, regarding the incidence of childhood leukaemia around the Dounreay Nuclear Establishment, made recommendations regarding a case-control study already being undertaken in the Dounreay area. Following publication of this study the Committee noted the finding of an apparent association between the use of the beaches in the proximity of Dounreay by children and the development of leukaemia and non-Hodgkin lymphoma (NHL), but advised that this finding should be interpreted with considerable caution. COMARE undertook to update its advice as further relevant research data became available, and subsequently requested more beach monitoring data from the appropriate authorities.

At COMARE's request, Her Majesty's Industrial Pollution Inspectorate (HMIPI) produced a document summarising the Dounreay foreshore monitoring since 1983. This described the finding of a number of radioactive metallic particles on the Dounreay foreshore between 1984 and 1990 and a single similar particle on Sandside beach in 1984. The United Kingdom Atomic Energy Authority had concluded that the contamination was the result of a spillage in 1965. COMARE raised queries about specific aspects of beach monitoring data and the nature, activities and location of the radioactive particles.

COMARE decided that a small working group should address these issues. The working group considered information provided by HMIPI and the Government Division of UKAEA and at the invitation of UKAEA visited the Dounreay site and the nearby beaches in May 1994. During this visit the working group were informed of new possible sources of contamination of the Dounreay foreshore. These issues fell within the RWMAC's remit and expertise and hence COMARE requested the RWMAC's assistance in establishing the source of radioactive contamination. The RWMAC agreed to this request and has, with the full co-operation of UKAEA and HMIPI, carried out an investigation into the source of the particles within the context of the wider contamination now recognised at Dounreay.

Although a single source cannot be unambiguously defined, the RWMAC take the view that there are strong indications of the location of the source of these particles and how they are being introduced into the environment. COMARE and the RWMAC believe that the investigations into the source of the particles, as well as the wider contamination, need to be pursued actively so that appropriate remedial measures can be put in place at an early date. The RWMAC is of the opinion that the most likely source for the particles is surface contamination adjacent to the top of the authorised Intermediate Level Waste Disposal Shaft, although other sources cannot be ruled out at this stage.

COMARE has noted that its authority relies on the accuracy and completeness of the information given to the Committee by responsible authorities. The Committee is concerned that the authority of its Second Report may have been diminished by the lack of timely relevant information concerning both the activity and source of the particles. This concern has been communicated to both UKAEA and HMIPI. COMARE has sought assurances from UKAEA that there is no other outstanding relevant information and that any information which may arise in the future will be disclosed.

* The RWMAC recommend that UKAEA should introduce into its advisory structure on this matter a greater level of appropriate, independent scientific expertise. In addition, public confidence could be enhanced by regular, independent reviews of progress.

* COMARE and the RWMAC agree that the Intermediate Level WasteDisposal Shaft at Dounreay is an unacceptable model for the disposal of radioactive waste, and recommend that UKAEA should take steps over a relatively short timescale to propose a solution and a timetable for the treatment of the waste in accord with modern standards.

* COMARE believes that possible health effects from the radioactive contamination in the environment around the Dounreay site depend upon the likelihood of encountering one of the radioactive particles and on the particle activity. The chance of a member of the public encountering a metallic particle is considered to be extremely small and COMARE is of the opinion, based on the evidence currently available, that whilst the most active particles could cause acute effects, the metallic particles are most unlikely to explain the observed excess of childhood leukaemia in the Dounreay area.

Bryn Bridges

Professor Bryn Bridges
(COMARE Chairman)

John Knill

Sir John Knill
(RWMAC Chairman)

STATEMENT BY THE:

COMMITTEE ON MEDICAL ASPECTS OF RADIATION IN THE ENVIRONMENT

RADIOACTIVE PARTICLES ON DOUNREAY BEACHES

BACKGROUND: COMARE'S SECOND REPORT

1. In 1986 Heasman et al (Lancet 1986; 1: 1266) reported that there was a marked excess of childhood leukaemia in the vicinity of the Dounreay Nuclear Establishment, run by the United Kingdom Atomic Energy Authority (UKAEA). The Secretary of State for Scotland asked the Committee on Medical Aspects of Radiation in the Environment (COMARE) to consider and advise on this and related issues. The Committee's advice was published in 1988 in their Second Report entitled "Investigation of the possible increased incidence of childhood leukaemia in the vicinity of the Dounreay Nuclear Establishment, Caithness, Scotland".

2. The final conclusion of this report (paragraph 5.27, p93), abbreviated here, stated:-

> "There is evidence of a raised incidence of leukaemia among young people living in the vicinity of Dounreay...... Conventional dose and risk calculations suggest that neither authorised nor accidental discharges could be responsible. There are, however, uncertainties about dose and risk calculations, especially with respect to exposure of the fetus and small child, high LET emissions and prolonged low-level exposure."

3. The COMARE Second Report recorded that particulate discharges had contributed to accidental discharges at the Dounreay Nuclear Establishment. The reassurance contained in the final conclusion of the Report relating to particles in the environment was based partly on the low level of radioactivity such particles might contain and in part on the very small chance of a particle being encountered by any member of the public.

4. In compiling this element of their report the Committee relied on information supplied in an UKAEA document which described the metallic particles found on the Dounreay foreshore as resulting from an accidental spillage which was hosed down into a storm drain. This spillage occurred in 1965. UKAEA said that storm damage to this drain in 1983 had resulted in the particles being released to the Dounreay foreshore. The document supplied by UKAEA quoted the following statement from an HM Industrial Pollution Inspectorate (HMIPI) report "In radiological terms the particles gave no grounds for concern. The total number

involved was small and the majority were found on the enclosed Dounreay foreshore, to which there is no public access. Even in the extremely unlikely event of one of the particles found at Sandside being ingested by a member of the public the radiation dose received is not likely to have exceeded a few per cent of the ICRP limit." This statement was also quoted in COMARE's Second Report (paragraph A3.14.ii., p66).

5. The Second Report made recommendations regarding the case-control study already being undertaken in the Dounreay area by Urquhart et al. Following publication of this study (BMJ 1991; 302: 687-692), the Committee noted (Hansard 21st March 1991) the finding of an apparent association between the use of the beaches in the proximity of Dounreay by children and the development of leukaemia and non-Hodgkin lymphoma (NHL), but advised that this finding should be interpreted with considerable caution. At the request of The Scottish Office, COMARE undertook to update their advice as further relevant research data became available, and subsequently requested more beach monitoring data from the appropriate authorities, the UKAEA and HMIPI.

6. COMARE set up a working group to appraise this monitoring data and other relevant information and to report back to the main Committee. The working group have held five meetings and visited the Dounreay site in May 1994, enabling its members to examine the foreshore and beaches and talk to the appropriate members of the Dounreay staff responsible for safety and monitoring procedures. In discussion at the working group meetings, inconsistencies in the data concerning the activities of the particles, caused members to express doubts on the veracity of the reported source. During the course of the working group visit to Dounreay it became apparent that the source of the particles quoted in paragraph A3.7 of COMARE's Second Report, as quoted from a document provided by UKAEA, had not in fact been established. As early as 1984 staff at UKAEA and HMIPI had considered a number of other possible hypotheses for the origin of the particles found on the foreshore, but these had not been communicated to COMARE. The Committee is concerned that neither these hypotheses nor estimates of the possible size of the accidental release were subjected to the rigorous scientific investigation which UKAEA should have undertaken.

Monitoring of Dounreay Foreshore and Sandside Bay

7. Detailed beach monitoring data provided by UKAEA in 1993 disclosed that, between 1979 and 1992, over 100 radioactive metallic particles had been found on the Dounreay foreshore. It was noted that, although it was difficult to gain access to the foreshore, it was not closed to the general public. The foreshore has only recently been fenced off to restrict further access. Further investigation has shown that these particles are of similar size and density to the coarse sand on the foreshore and that the average number found each year is not declining. The particles have estimated activities of up to 10^8 Bq* of caesium-137,

* Levels of radioactivity are measured in units called *becquerels* (Bq).

with most of the particles having between 10^6 and 10^7 Bq. A single metallic particle with an activity of approximately 10^5 Bq had been found on the public beach at Sandside Bay in 1984. It was expected that these particles would also contain comparable amounts of strontium-90 and yttrium-90. This was confirmed by subsequent radiochemical analysis. The COMARE working group pointed out that one particle found on the Dounreay foreshore had a comparable level of radioactivity equivalent to the estimate of the size of the entire accidental release originally provided by UKAEA and used as the basis for the conclusions in the Second Report quoted above. The statement taken from the HMIPI report relates mainly to the metallic particle and other particulate releases of different composition and activity found at Sandside Bay. These particles were generally of much lower activity than the majority of those found on the Dounreay foreshore.

8. The authority of COMARE relies on the accuracy and completeness of information given to the Committee by responsible authorities. COMARE is deeply concerned that the authority of its Second Report may have been diminished by a lack of timely and relevant information. The Chairman has communicated this concern both to UKAEA and to HMIPI, and COMARE has sought assurances from UKAEA that no other information relevant to the environmental releases remains outstanding and that any relevant documentation or information which might arise in the future will be disclosed.

Revised NRPB estimates of dose and health effects

9. The possible health effects from these particles depend on the likelihood of encountering them and on the particle activity. The National Radiological Protection Board (NRPB) has calculated the radiation doses a member of the public might receive in the unlikely event that such particles were encountered. They considered the health consequences of an individual inadvertently swallowing a particle and also the effect of prolonged contact on the skin.

* The activity in the particle found at Sandside Bay was at the lower end of the observed range (10^5 Bq) . If such a particle was swallowed the estimated doses would be of the same order as those received every year by the average person in the UK from background radiation, which is 2.5 millisieverts (mSv). Much higher localised doses could result if such a particle were in prolonged contact with the skin or a specific point in the gut. Contact times of about an hour to $1cm^2$ of skin could result in a dose equivalent of about 1000 mSv (1 Sievert [Sv]), sufficient to give rise to acute effects such as inflammation or ulceration. Such effects would occur following shorter contact times for more active particles. There is also a risk of late health effects such as leukaemia where the

probability of occurrence depends on the activity ingested. In the case of the particle found at Sandside Bay, the increased risk would be extremely small.

* However, only a very few particles have been found with activities lower than 10^5 Bq, with some having activities as high as 10^8 Bq. The majority of the particles found so far have activities in the range of 10^6 to 10^7 Bq. Any resultant doses from ingestion of particles with these levels of activity would give an equivalent bone marrow dose of tens of mSv, sufficient to cause a significant increase in the risk of leukaemogenesis. In the unlikely event that a particle similar to the most active particle found on the Dounreay foreshore was swallowed, the dose equivalent to the intestine could be tens of Sv, a dose likely to cause severe acute effects. The dose to the red bone marrow would be in the region of hundreds of mSv, sufficient to increase significantly the probability of leukaemogenesis over a number of years. Such a particle could cause severe acute radiation effects at points of prolonged contact.

10. COMARE is concerned that the activities and potential doses from contact with the particles are considerably higher than those quoted in its Second Report. However, the Committee wishes to emphasise that even though these potential radiological doses are higher than implied in its Second Report, the chance of encountering such particles was and remains extremely small. Parts of Sandside Bay have been monitored on a fortnightly basis since the original metallic particle was located and removed in 1984; no particles have been found on the public beach since that time. Given that only one particle has been found on a public beach we consider the chance of an individual encountering them is extremely small. Because of the very low probability of encountering such particles, the Committee is of the opinion, based on the evidence currently available, that whilst the most active particles could cause acute effects, the metallic particles are most unlikely to explain the observed excess of childhood leukaemia in the Dounreay area.

COMARE's response to monitoring data and dose estimates

11. Sandside Bay must contain an enormous number of sand grains of similar size to the particles. This might mean that, given the difficulty of finding a small number of particles amongst so many others, there may be more than one metallic particle still on the beach. However, given that the dilution factor is so large this must render the likelihood of a member of the public encountering a particle very small. Nevertheless, COMARE remains concerned about the continued appearance of the particles on the Dounreay foreshore, and COMARE has therefore recommended that beach monitoring is increased on the public beaches close to

Dounreay after heavy storms when there is maximum disturbance of the beach and buried particles have the best chance of being detected. We understand that this is now being done.

RWMAC investigations

12. COMARE is aware of the recent changes that have been made in the senior management of UKAEA Dounreay and welcomes the fact that the overdue review of site practices is now being undertaken. The Committee is also aware that appropriate actions are now being carried out by UKAEA and HMIPI to investigate the source of these particles and identify any remedial action which may be necessary to ensure that there are no further releases to the general environment.

13. Despite the actions put in hand by UKAEA and HMIPI, COMARE remained concerned that the source of the particles had not yet been identified and, therefore, requested that the RWMAC should report on the possible source or sources of the particles found on the Dounreay beaches, with particular reference to the role of the Intermediate Level Waste Disposal Shaft. The results of RWMAC's investigations are reproduced in the second part of this publication.

14. We note that RWMAC has confirmed that there is a large source of particles and that RWMAC's main conclusions are as follows:

* The most likely reservoir of the particles is the turfed soil which covers the low cliffs close to the top of the shaft and which feeds onto the foreshore as the result of erosion. Other sources could have contributed particles on to the beach and these cannot be eliminated at this stage.

* The particles were probably spread onto the ground surface adjacent to the shaft area by the 1977 explosion and the untidy disposal of waste down the shaft.

* The investigations into both the source of the particles and the wider contamination are now being pursued rigorously. New management structures have been introduced but wider scientific expertise and independent review systems are required.

* The Intermediate Level Waste Shaft is not an acceptable model for the disposal of radioactive waste. The shaft is likely to be breached by natural erosion within the next hundred years or so. It is difficult to identify any technical solution for in situ immobilisation of the waste which can be assumed to be fully satisfactory.

* Progressive steps should be taken, over a relatively short time scale, to evaluate the situation fully and propose a solution and a timetable for the treatment of the waste in accord with modern standards. This is likely to require the retrieval of the waste and its repackaging for disposal elsewhere, to be followed by decontamination of the shaft and its de-authorisation for disposal. The RWMAC has been advised that the UKAEA will be undertaking a review of options for the shaft.

COMARE Recommendations

15. COMARE welcomes the results of the RWMAC's investigations as being most constructive and in particular the fact that investigations into both the source of the particles and the wider contamination are now being pursued rigorously. However, COMARE notes with concern that the Intermediate Level Waste Shaft is likely to be breached by natural erosion within the next 100 years or so. COMARE endorses strongly the RWMAC recommendation that UKAEA acts urgently to evaluate the situation fully and to put in place a modern waste management regime for the Intermediate Level Waste Shaft.

16. COMARE notes that despite the existence of a number of hypotheses the source or sources of the particles found on the foreshore has not yet been definitively established. COMARE recommends that investigations are carried out to determine whether or not there are other possible particle sources other than the shaft or methods of spread of other contamination to the general environment. COMARE also notes the RWMAC suggestion that abrasion of the particles in the natural environment will not entirely remove them from that environment and could make them more mobile. This suggestion requires further investigation for it to be confirmed or refuted. COMARE recommends that environmental monitoring and other appropriate action is continued until the source and nature of all the particles are finally discovered and dealt with satisfactorily. At the request of The Scottish Office, COMARE will continue to keep the situation under review and will consider whether there is a need for a further statement of advice regarding any possible implications concerning the conclusions of its Second Report.

THE RADIOACTIVE WASTE MANAGEMENT ADVISORY COMMITTEE:

REPORT TO THE COMMITTEE ON MEDICAL ASPECTS OF RADIATION IN THE ENVIRONMENT

Introduction

1. The Radioactive Waste Management Advisory Committee (RWMAC) was approached in June 1994 by the Committee on Medical Aspects of Radiation in the Environment (COMARE) with the request for assistance in determining the sources of metallic radioactive particles which had been found since 1979 on the beaches adjacent to the Dounreay Site of the Government Division of the UK Atomic Energy Authority (UKAEA). The COMARE requested that the RWMAC gave particular consideration to the role of the Intermediate Level Radioactive Waste Disposal Shaft as a potential source. The RWMAC agreed at its meeting on 30 June 1994 to carry out such a study and established a Working Group to visit Dounreay, and to carry out the investigations on the Committee's behalf.

2. The RWMAC approached Her Majesty's Industrial Pollution Inspectorate (HMIPI) through The Scottish Office with a request that arrangements were made for a site visit. HMIPI requested that such a visit be delayed until a report, under preparation by UKAEA, was completed. It was expected by the RWMAC that this report would provide an indication of the likely particle source and details of the further investigation programme.

3. The RWMAC acceded to this request and considered the UKAEA report[1] at its meeting on 10 November. The Committee felt that the UKAEA report was inadequate for its purpose, did not advance matters significantly, and there was lack of clarity as to the forward investigative programme. It was decided that a visit to Dounreay was now required.

4. The Chairman, two Members and the Secretary spent 26 and 27 January 1995 at Dounreay when presentations were made by UKAEA and site inspections carried out. Subsequently UKAEA has provided additional documentary material. A draft of this report was submitted to HMIPI, and to UKAEA, for factual comment, and to ensure that any factual errors were corrected. The report was approved by the RWMAC at its meeting on 30 March 1995 for transmission to the COMARE.

5. Throughout this exercise the RWMAC has maintained close contacts with the COMARE and this has been particularly assisted by Professor Keith Boddy who is a Member of both Committees. The Chairman and the Secretary

met Dr Tom Wheldon, the Chairman of the COMARE Dounreay Beach Monitoring Working Group, on 25 January 1995. It was agreed at that meeting that the terms of reference of the RWMAC study should be:

> ***To report on the possible source or sources of the particles found on the Dounreay beaches, with particular reference to the role of the Intermediate Level Waste Disposal Shaft.***

6. The RWMAC is very grateful to HMIPI and to UKAEA at Dounreay for the positive and helpful approach developed throughout this study.

The Particles

Particle types

7. Various types of radioactive particles have been found, at different times, on the Dounreay beaches and these have included:

- Fragments of Material Test Reactor (MTR) fuel consisting of uranium and aluminium
- Black tarry agglomerates
- Contaminated stones
- Activated steel

8. The fragments of uranium/aluminium ((U/Al), uranium/alloy associated with aluminium cladding), are the most significant particles numerically and radiologically, and are the particles whose source the COMARE wished the RWMAC to examine. Future reference to "particles" will be in relation to these materials. It should be noted that the activated steel particles have been found at similar locations to the U/Al particles and have similar activities.

Nature of the uranium/aluminium fragments

9. These fragments are most probably derived from the milling of the aluminium cladding to MTR Fuel Elements which was carried out during the 1960s. Small pieces of uranium could well have been milled away at the same time with the aluminium to create the type of metallic mix found in the particles.

10.. The particles found on the beach have a typical maximum dimension of about 1 mm, and a typical mass of 0.005 gm; some particles are slightly larger, and some smaller. The particles are well-rounded with smooth surfaces and this is almost certainly the result of abrasion by sand and pebbles.

11. The particles have been subject to gamma-spectrometry and the radiological component has been shown to be dominated by Caesium-137 (Cs-137). It has been possible to date the particles by determining the Cs-137 to Cs-134 ratio (Cs-134 decays more rapidly than Cs-137). The date of irradiation has been shown to be typically 1964 with a range of 1962 to 1967.

Activity of particles

12. The particles range from 7.4×10^1 to 2×10^8 Bq in activity, with most particles between 10^6 and 10^7 Bq. The 14 particles found in 1994 ranged from 1.7×10^5 Bq Cs-137 to 8×10^6 Bq Cs-137.

Location of particles

13. The particles have been found, over a period of years, in the following locations:

- Dounreay foreshore
- Sandside Beach (only one particle, found in 1984)
- Dounreay Site

14. Until immediately prior to the visit by the RWMAC virtually all the particles had been found on beaches. Although at least two particles were found within the Site in the period 1979-81 and, over the years there were other finds, the discovery of significant numbers of clustered particles within the Dounreay Site is recent, and is later than the original reference of this matter by the COMARE to the RWMAC.

15. The particles have been found mainly, in sandy and gravelly areas, spread along the Dounreay foreshore east of the Dounreay Fast Reactor (DFR) and west of the eastern limit of the Dounreay Site.

Rate of discovery of particles

16. The earliest documented finding of a particle was 1979 and two others were recorded up to November 1983 when a systematic beach monitoring programme was introduced. The monitoring since 1983 has revealed particles on an annual basis, as set out in the Table overleaf.

17. One further particle has been found on the foreshore in January 1995. Several particles have been found by excavation of trial cores into the ground surface in the vicinity of the top of the shaft in late 1994 and early 1995. There has been an average of about 13 finds on the foreshore per year, and if the very high

find rate in January 1984 is omitted, then the rate is about 12 finds per year. There is a marked difference of find rate in Winter and Summer, with (omitting January 1984) 8 each Winter and about 4 each Summer. Only one find has been discovered outside the shore frontage of the Dounreay Site and this was Sandside Bay in 1984.

Table: annual distribution of particle finds

Year	Winter*	Summer*	Total
1984	23	3	26
1985	8	2	10
1986	14	3	17
1987	5	5	10
1988	7	4	11
1989	5	10	15
1990	9	2	11
1991	9	4	13
1992	0	4	4
1993	4	9	13
1994	11	2	13

* Winter is based on the period October to March, and Summer based on the period April to September.

Evidence for continuing release

18. The overall consistency in the rate of discovery of the particles, recognising the standard pattern of monitoring, indicates that a reservoir of such particles is almost certainly present which is releasing particles into the environment at a relatively steady rate. The seasonal variation in rate of discoveries suggest that storm conditions may be a factor in delivering particles onto the foreshore.

19. The particles, being largely composed of aluminium, are relatively soft and, as demonstrated by their rounded, polished form, they will abrade relatively

quickly in an energetic marine environment. However, no abrasion tests have been carried out as yet on similar materials. The find rate in 1984 was twice that of the longer term average. The large number of discoveries in the first three months of 1984 could suggest the possibility that a previous year's supply of particles was still waiting to be discovered. If such a conclusion was valid then it would imply that the maximum life of a particle on the foreshore is two to three years. No older particles would occur because they would have been worn away or dissolved.

20. Such a maximum residence time of a particle on the beach, although speculative, is broadly consistent with the abrasion characteristics which one would expect of particles of minerals with similar hardness properties. If that is so, then the reservoir of particles must be within an environment where the particle is not subject to wear until it is released onto the foreshore. This would imply in turn that either the reservoir is terrestrial, or that it is a protected marine environment, such as an offshore sand bar, which is generally not subject to erosion. The latter conclusion would appear somewhat implausible in the context of the very active nature of the marine environment offshore Dounreay.

21. Nevertheless, abrasion of the particles will not entirely remove them from the natural environment in the short-term, they will simply become smaller and might be more readily transportable. If a re-concentration mechanism existed in the marine environment, then contamination could result.

22. A study was carried out by the RWMAC of the annual aquatic environment reports (1965 to 1993) and a compilation of all the data (1986 to 1993) of the Directorate of Fisheries of the Ministry of Agriculture, Fisheries and Food (MAFF) relevant to Dounreay. This study of the MAFF data has not shown major variance. However, there is one set of anomalous results in 1986 which could be related to the Chernobyl incident. Anomalies were also identified from the 1988 data which the UKAEA recognised as the "Oigin's Geo incident" of December 1988. A report on this incident was provided to the RWMAC and it would not appear to be related to the subject matter of this report.

Possible Release Mechanisms for Particles

Introduction

23. There are two basic mechanisms whereby the particles could be released to the environment on a continuing basis. *Either* there have been a specific release or releases into the environment associated with one or more past events at the Site which have created a reservoir or reservoirs of particles somewhere which continue to be depleted *or* there is a continuing release from one or more sources within the Site.

24. It is apparent from the discussion in the previous section (paragraph 19.) that it is unlikely that there is a reservoir of particles in the high energy, marine environment as the particles would be broken down within a relatively short period, possibly as little as two to three years. Equally any particles contained in the many crevices in sandstone bedrock of the foreshore are likely to be trapped and incapable of being, in general, released. One or more onshore particle reservoirs appears most probable and the alternative sources of the particles will now be considered.

DMTR-DFR pipe rupture in 1965

25. In 1965 demineralised water was being transferred from the DFR to the Dounreay Materials Test Reactor (DMTR) fuel pond using temporary piping. A spillage occurred when the pipe was fractured by a lorry close to the top of the shaft. It is possible that some particles were syphoned out of the DMTR pond. The road surface was flushed down by the Site fire brigade. It is also possible that some particles, which had at the time an assessed total activity of 1.85×10^8 Bq (this is now considered an unreliable figure), went into a drain close to the cliff face, remaining there until 1983 when the cliff was eroded by a storm.

26. This incident has some importance in relation to the background to this report. At the time of writing the Committee's second report[2] COMARE were told by the then-UKAEA of this incident which was used to explain the occurrence of particles on the foreshore. However, the COMARE Working Group recognised in 1992 that the total activity of the particles by then found on the foreshore was well in excess of the previously assessed total activity for the particles then assessed by the UKAEA. Indeed one particle had already been discovered with an activity equivalent to the previously assessed total.

27. The incident had been regarded for some years, at Dounreay, as a plausible mechanism for explaining the source of the particles. This is clearly no longer tenable although some particles found on the foreshore might have originated this way.

The Intermediate Level Waste Disposal Shaft: explosion in 1977

28. A violent explosion took place in the 65 m deep, 4.6 m diameter, Intermediate Level Waste Disposal Shaft in the early hours of 10 May 1977. The subsequent investigation established that this event had been caused by the addition of a minimum of 2 kg of sodium and potassium which reacted with the water in the shaft to produce a hydrogen explosion in the gas space at the top of the shaft. Ignition would have been caused by the sodium and potassium coming in direct contact with water.

29. The explosion resulted in extensive damage to the top of the shaft, the concrete roof slab and steel adaptor plates had been blown off, and some of the surrounding 5 ton concrete blocks were displaced and badly damaged. The steel top plate to the shaft had been blown a distance of 12 m.

30. Some waste was expelled from the shaft resulting in surface contamination. At the time the wind was blowing offshore and an observer saw a white plume of smoke being blown towards the sea. The incident report refers to scaffolding poles, about 6 m in length, being found 25 and 40 m away from the shaft. Oral references were made to the RWMAC Working Group of the occurrence of irradiated breeder reflectors made from either nickel or steel in the form of rods impaled into the ground having been expelled from the shaft. There is no such reference in the incident reports made at the time and it is possible that the conversion of scaffolding poles to "rods" has grown as a part of Dounreay Site mythology.

31. It is understood that the solid material expelled was dumped down the shaft which has not been used for disposal since. The incident report indicates that the area surrounding the shaft was cleared of contamination and debris by the end of the afternoon of 10 May, less than 24 hours after the event. It is also known that soil was subsequently removed up to several weeks afterwards.

32. Both the COMARE Working Group when it met at Dounreay in May 1994, and the RWMAC during at least one previous visit to Dounreay, had been told that there was no contamination associated with the 1977 explosion. The COMARE Working Group was also told, during its 1994 Dounreay visit, that the shaft explosion was now considered a possible source of the particles. The incident was not mentioned in a letter of August 1987 from UKAEA to the Department of Health and Social Security detailing "unplanned discharges" in connection with the drafting of the COMARE's second report. It is understood that UKAEA at that time did not consider the shaft explosion to be an "unplanned discharge" as defined because there was no discharge beyond the Site boundary. However, there is contemporary evidence in the incident reports that material was flung beyond the Site fence. Monitoring was carried out outside the Site boundary, and the contaminated items retrieved.

33. The current position is that the UKAEA regards the area around the top of the shaft as contaminated. Investigations, which have not yet been reported in detail, have revealed an area of contamination both at the surface and at depth, and both inside and outside the Site boundary, in the vegetated ground around the top of the shaft. Trial cores have identified a number of the particles which have similar physical and radioisotopic characteristics to the particles found on the beach except that they are rough, demonstrating tensile fracture patterns in contrast to the rounded, polished particles found on the beach. One particle was from a fast reactor fuel source of a type known to have been deposited down the shaft. The

precise distribution and relative concentration of these particles around the top of the shaft is still to be determined. Preliminary volumetric samples indicate that the data would extrapolate to a much larger number of particles around the shaft than on the beach.

Cleaning of sea effluent pipeline upstands in 1983

34. A large number of black tarry agglomerates were found on the shore at Sandside Bay, the Dounreay foreshore and Oigin's Geo in 1984 and this incident was traced back to the operations of a low active waste incinerator. The agglomerates, which floated, had been transferred to the sea by the main effluent pipeline and were returned back to the shore naturally. UKAEA has reported that filtration has successfully eliminated this source of agglomerates.

Inactive drain system

35. This system discharges directly onto the foreshore but, if particles were to be entering into these drains, then the mechanism is unknown. However, water could wash particles off the roads down the drain thereby transferring them onto the beach.

Low active drain systems

36. The Fuel Cycle Area low active drain was replaced between 1975 and 1981. The possibility exists that there is a cache of particles in the old system which might reach the environment through the effluent pits. The flow rate through the old drain system is low and, although this is an unlikely continuing source of the particles, it should not be eliminated from further studies.

Wider site contamination

37. During the past few months wider contamination, than had been previously acknowledged, has been recognised to exist at Dounreay. Active steps are being pursued by the Dounreay management to assess the extent of contamination and the measures which now need to be taken. The existence of such wider contamination does not provide a source mechanism for the particles in itself but it does suggest that past waste management practices may have provided a culture which contributed to release of particles into the environment.

Low Level Waste Pits

38. The Low Level Waste Pits are known to contain some MTR millings and it is possible, but unlikely, that particles are being transported from the pits to the low active drain system via the engineered pumping system.

Spoil tips

39. Contamination has been found on waste tips at the eastern end of the Dounreay Site. Although, it was considered possible that these tips contain particles, and as they eroded particles could carried to the foreshore, UKAEA now consider this a remote possibility.

Intermediate Level Waste Disposal Shaft

40. The possibility that particles contained in the Intermediate Level Waste Disposal Shaft pass through the surrounding rock onto the adjacent foreshore will be considered in the following section.

Role of the Shaft

Geology of the shaft location

41. Dounreay is located close to the southern margin of the Orcadian Basin of Devonian age. The Site is underlain by well-bedded sandstones of the Latheron Sub-group of the Caithness Flagstone Formation which dip gently seawards to the north west at 8 to 12°. The rock mass is noticeably jointed with both north west-south east (dip) and north east-south west (strike) joint sets (Figure 2). As a result the strata are broken into large, roughly rectangular, blocks. Some thin crush zones parallel the joint sets. The faults, which are represented by wide zones of more closely fractured rock, possibly several metres wide, are orientated parallel to the main joint sets.

42. The rock structure is well-displayed on the Dounreay foreshore with the fault zones eroding out as narrow gullies which extend up on to the beach.

History of the shaft

43. The shaft was originally excavated during the Spring and Summer of 1956 in order to provide access to an adit which joins the inclined tunnel which provides the means of discharge to the sea of the main effluent pipeline. The spoil from the shaft was tipped at the surface next to the top of the shaft and in the intervening years some of this material has been eroded away by the sea. The shaft was constructed to a design diameter of 4.6 m to an elevation of -53.5 m OD giving a total shaft depth of 65.4 m. The connecting adit linking the base of the shaft to the effluent pipeline tunnel has been plugged by a 2.4 m concrete bulkhead 19.8 m from the shaft base. This bulkhead has been remotely inspected in recent years and is believed to be in a sound condition. If the bulkhead was defective then this would be a source of particles, through the tunnel and into the sea offshore. The uppermost 7 m of the shaft is lined.

44. During the driving of the effluent tunnel under the sea considerable water inflows were encountered under about 10 to 30 m of rock cover. Much of this water inflow came through joints, some of which were described as "open". It is believed that the tunnel did not penetrate to its design length in view of the extent of water flow encountered.

45. Waste disposal into the shaft began on 30 June 1959 and continued up till the end of 1971; smaller amounts were emplaced in 1973, 1974 and 1977. The Site is an authorised disposal site, disposal being authorised on the basis that the level of water in the shaft is kept by pumping below -1.1 to -2.0 m OD (the minimum estimated tide level is -2.7 m OD). The water is pumped from the shaft through a filter into the low activity drain and thence to the sea through the effluent pits and the tunnel to the sea. No particles have been found in the filters. The pumping was interrupted for a short period in 1977 at the time of the explosion, and in 1984-85 when site investigations were underway around the shaft.

Waste emplacement methods

46. The raw waste which was disposed of in the shaft was carried to the site in a waste package suspended by a rope and contained in a open-bottom flask. The flask was placed over the shaft, the rope was cut and the package fell into the shaft. In view of the variety of material disposed of in the shaft the packages were often open-topped cans. The MTR fuel element swarf was contained in both 6 and 9 cm diameter aluminium cans with threaded caps inside the flasks. The current Dounreay management accepts that this practice might conceivably have resulted in very occasional small spills of material while en route to the shaft, or accidental spillage around the top of the shaft while emplacement was under way.

Waste inventory

47. The waste inventory involves a long list of items including contaminated equipment, tools, chemical equipment and chemicals, filters, gloveboxes, ducting, fuel element components and swarf, irradiated natural uranium fuel elements, radioactive sources, incinerator ash, building materials, sludges, borated glass, clothing of different types and wooden fire doors. Possibly two thirds of the material volumetrically was dumped down the shaft in the period 1962 to 1967. It is uncertain exactly where any particulate material is located in the shaft at the present time, or its current physical state; much of the waste may be in the form of sludge. It is also not known how far the waste has penetrated along the connecting adit towards the concrete bulkhead.

48. Waste, including floating items, is visible at the water surface to the shaft.

Hydrogeological investigations

49. There have been two significant investigations into the hydrogeology of the vicinity of the shaft, both of which have been carried out by the British Geological Survey, in 1978 and over the period 1984-85[3&4]. These investigations have been directed to a general understanding of the hydrogeology of the Dounreay Site in relation to the management of waste disposal sites. Particular attention has been given to the need for continued pumping in the Intermediate Level Waste Disposal Shaft and the possibility of in situ encapsulation of the waste in the shaft.

50. The hydrogeology of the shallow groundwater system in the Dounreay area is essentially simple with the groundwater flowing essentially from south to north being locally affected by the topography and pumping. Observations during the construction of the main effluent tunnel indicated that most groundwater flow was fracture flow occurring along joints and crush zones, and not along bedding planes. No major faults were encountered in the tunnel but they exist near the shaft and it must be expected that they would be water-bearing.

51. Hydraulic conductivity measurements for the Site as a whole indicated a range of values of 3×10^{-7} to 2×10^{-4} m/s with an average measured value of 5×10^{-6} m/s[3] and, for the vicinity of the shaft, a range of 10^{-8} to 10^{-5} m/s with most values at around 10^{-6} m/s[4]. Higher values might be expected in fault zones. A relatively small number of fractures within the boreholes dominated the hydraulic conductivity measurements.

Possible movement of particles through the rock mass

52. For a particle to move from the shaft into the surrounding rock it would have to move through the natural fractures within the rock mass. Theoretical calculations can be made which relate fracture frequency, aperture (space between the sides of the fracture) and hydraulic conductivity. Assuming that all flow was concentrated in parallel-sided bedding fractures spaced at 5 m intervals, then the possible range of apertures is 0.01 to 0.45 mm for the range of hydraulic conductivities[4]. In the real world fractures are not perfectly parallel-sided and so it would have been difficult for even tiny particles, far smaller than those found on the beach, to have passed through the rock mass. In these circumstances it is clear that particles 1 mm or more in size could not have been transported along individual fractures.

53. There is, however, an alternative scenario in that the intersection between a dip joint and a bedding fracture would form a linear feature plunging gently north west from the shaft towards the sea (Figure 2). Such a linear feature could form a pipelike form within the rock mass thereby channelling the water in

hydraulic terms. If such features were the only water-transmitting structures in the rock mass, and they occurred within the rock mass at 5m intervals, then the theoretical calculation, for the highest hydraulic conductivity$_4$, would yield a pipe diameter of 4 mm. Modern research into fracture flow recognises that much groundwater flow is channelled within the plane of fractures and pipelike flow systems may not be exceptional. The possibility exists, although it is unlikely, that particles of 1mm in size might be carried along pipe-like features formed at joint-bedding fracture intersections.

54. In order for the particles to move from the shaft towards the sea, there would have to be a hydraulic gradient encouraging movement in that direction. In fact, the local groundwater flow regime around the shaft is significantly influenced by the dewatering which draws down the water table into the shaft by about 7 m relative to the unperturbed situation. In addition, the rock around the construction adit is drained to a water head equivalent to the then-current sea level. In these circumstances there is no driving head tending to move the particles out of the shaft into the surrounding rock. Such a driving head would have only occurred at a short time after the explosion in 1977, and for a period during the investigations in 1984-85. The explosion might have disturbed the waste to some degree but the effect would have been transient and much of the particulate matter was buried at some depth within the waste. Nevertheless it is known from the borehole investigations that part of the rock around the shaft is contaminated although is unlikely to have been caused by the presence of particles.

55. It is also apparent that other types of waste material present in the shaft, together with the MTR swarf which provided the particles, might have been expected to be present as particulate matter on the foreshore if the shaft were the primary source of the particles.

Discussion

56. It is apparent, therefore, that the particles are generally likely to be too large to move from the shaft through the rock mass onto the foreshore and that the current pumping regime would militate against such particulate movement even if it could occur. There is the theoretical possibility that particles could move along pipelike features at joint-bedding fracture intersections but it might then be expected that other forms of particulate matter would also be present on the foreshore. The pipe mechanism of particle movement through the rock cannot be dismissed but it is unlikely.

57. The consideration of containment of particles within the shaft has demonstrated that the shaft, as well as its proximity to the coast, is not an acceptable model for the disposal of intermediate level waste. The shaft is very close to the cliff which is subject to strong wave attack and it is likely to be breached within

the next hundred years or so. As it is improbable that the waste could be immobilised in situ, progressive steps should be taken, over a relatively short timescale, to fully evaluate the situation and propose a solution in accordance with modern standards. This requires a radical reconsideration of the safety of the shaft in the long-term and the solution is likely to require the phased retrieval of the waste, its packaging for disposal elsewhere, and the decontamination of the shaft, and its deauthorisation for disposal. The timetable to complete whatever steps need to be taken should be published. The RWMAC has been advised that a review of options is to be carried out by UKAEA and this is likely to be available in about three months time.

Source of the Particles

58. On the present evidence, the source of the particles is most likely the turfed soil which covers the low cliffs close to the top of the shaft and outside the Site boundary (Figure 1). These cliffs, which are composed of soft glacial materials, are undergoing erosion so that the soil and turf falls on to the beach regularly. The erosion of the cliff is likely to be most rapid in the winter.

59. The particles were probably spread onto the ground surface adjacent to the shaft area by the 1977 explosion, and probably previously by untidy disposal of waste down the shaft. The clean-up following the 1977 explosion may have spread the particles-laden contamination more widely around the Site.

60. There could well be other sources of particles within the site but these are less likely to provide, or have provided, a large reservoir from which a steady flow of particles onto the foreshore could have arisen. Nevertheless it remains important to establish all potential reservoirs of particles.

Future Actions Related to the Particles

61. The RWMAC has been impressed by the rigorous manner in which the investigations into both the source of the particles and the wider contamination are now being pursued. New management structures have been introduced to plan and monitor progress. However, the membership of the Dounreay Safety and Environmental Steering Group which is dealing with this action is largely internal and does not have the scientific expertise to address all the issues which have been posed. For, example knowledge of near-shore sedimentological, and soil, processes are essential.

62. The progress of the investigations and the development of remedial measures will necessarily be a long-term project. In these circumstances, public confidence would be enhanced by a review at annual intervals by an independent body.

63. The RWMAC had reviewed with UKAEA the current programme of investigations and made some suggestions for additional work which needs to be done.

Conclusions

* The most likely reservoir of the particles is the turfed soil which covers the low cliffs close to the top of the shaft and which feeds onto the foreshore as a result of erosion. Other sources could have contributed particles onto the beach and these cannot be eliminated at this stage.

* The particles were probably spread onto the ground surface adjacent to the shaft area by the 1977 explosion, and the untidy disposal of waste down the shaft.

* The investigations into both the source of the particles and the wider contamination are now being pursued rigorously. New management structures have been introduced but wider scientific expertise and independent review systems are required.

* The Intermediate Level Waste Shaft is not an acceptable model for the disposal of radioactive waste. The shaft is likely to be breached by natural erosion within the next hundred years or so. It is difficult to identify any technical solution for in situ immobilisation of the waste which can be assured to be fully satisfactory.

* Progressive steps should be taken, over a relatively short timescale, to fully evaluate the situation and propose a solution and a timetable for the treatment of the waste in accord with modern standards. This is likely to require the retrieval of the waste and its repackaging for disposal elsewhere, to be followed by the decontamination of the shaft, and its de-authorisation for disposal. The RWMAC has been advised that the UKAEA will be undertaking a review of options for the shaft.

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3 J H Black 1988 The Hydrogeology of Dounreay Nuclear Power Development Establishment. Institute of Geological Sciences.

4 T P Gostelow 1985 Hydrogeological investigations at the Dounreay Nuclear Power Development Establishment: 1984-1985. British Geological Survey.

Figure 1 **Diagrammatic representation of the distribution of metallic particles adjacent to the Dounreay intermediate level waste disposal shaft**

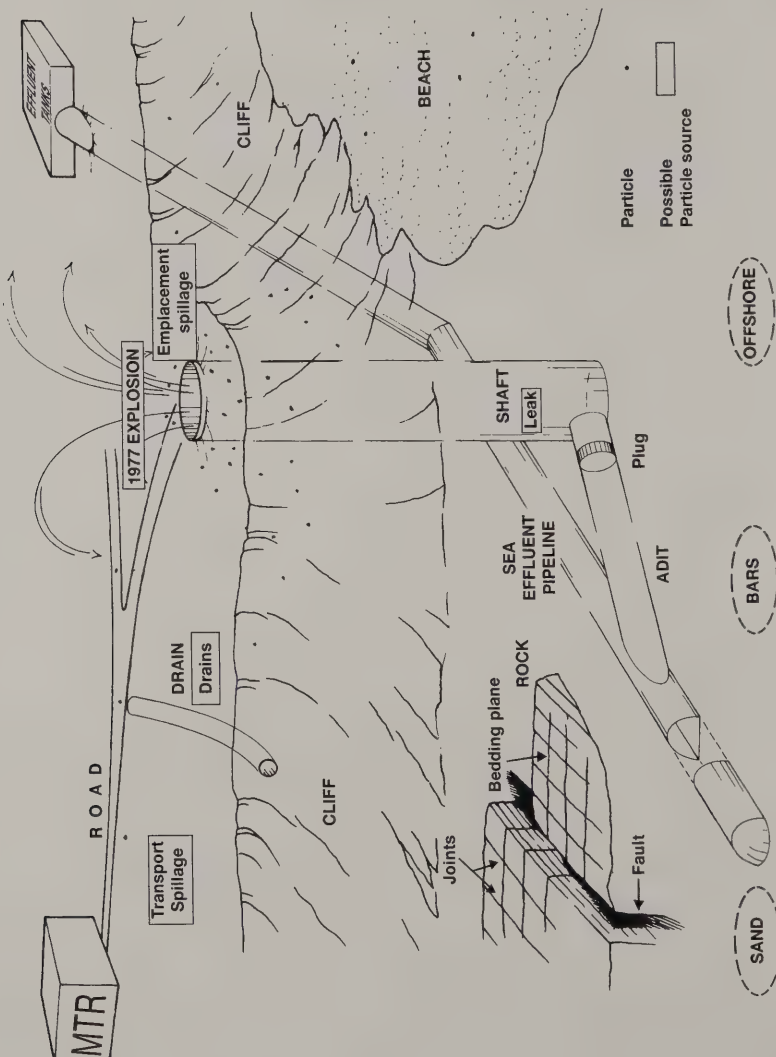
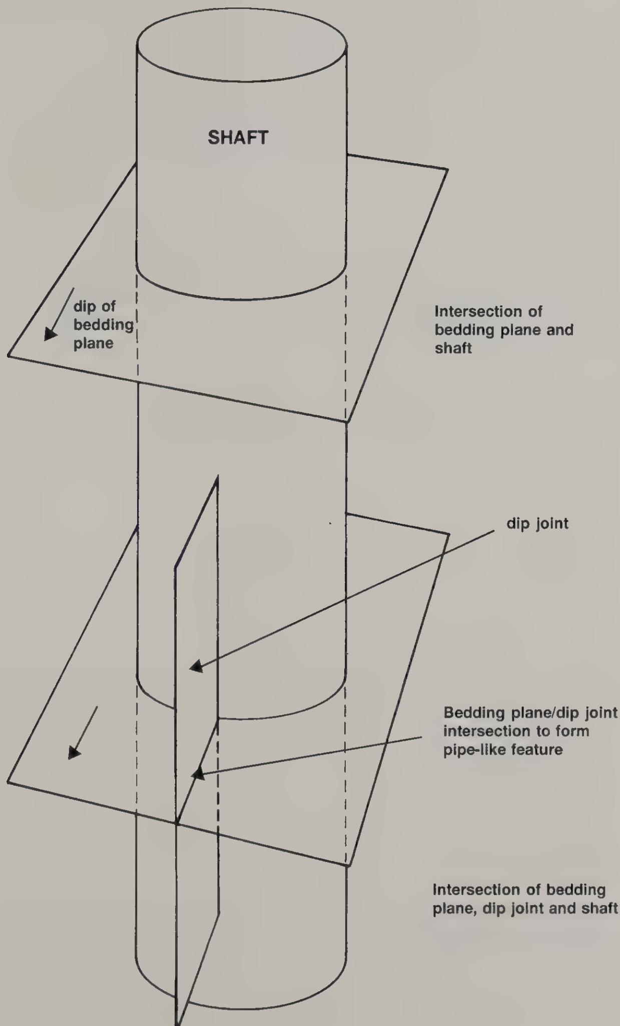


Figure 2 **Illustration of intersection between bedding planes and dip joint with shaft**



ANNEX 1

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COMARE is an independent expert advisory committee with members chosen for their medical and scientific expertise. The Committee offers Government independent medical and scientific advice on the health effects of ionising and non-ionising radiation in the environment, whether natural or manmade. The Secretariat is provided jointly by the Department of Health and the National Radiological Protection Board.

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"to assess and advise Government on the health effects of natural and man-made radiation in the environment and to assess the adequacy of the available data and the need for further research".

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